P2.2 THE METEOROLOGICAL AND RANGE SAFETY SUPPORT (MARSS) SYSTEM: A GIS-BASED TOOL FOR LAUNCH AREA HAZARD PREDICTION AND VISUALIZATION

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1. INTRODUCTION

The Meteorological And Range Safety Support (MARSS) system provides the Air Force and NASA safety and meteorological user communities at Cape Canaveral Air Force Station (CCAFS), Patrick Air Force Base (PAFB), NASA Kennedy Space Center (KSC), and Vandenberg Air Force Base (VAFB) with an integrated, responsive, and near real-time capability to analyze, predict, and assess the potential toxicological and blast damage hazards associated with Eastern Range (ER) and Western Range (WR) launch and range operations.

MARSS consists of a data acquisition component and a display component. The data acquisition component (known as the preprocessor or PPRO) retrieves measurements from the sensors, reformats them, performs a statistical quality control analysis and then archives and disseminates all results to the display component (known as the Monitoring and Display Station or MDS). The two components may be operated on the same physical computer or on separate computers. There is no explicit limitation to the number of display systems in the network and each is independent of all other systems. The acquisition component monitors the communications status of all workstations in the network, automatically retransmits data to any workstations with communication failures or other data transmission errors, and saves old data to archive media (currently digital tape).

Mesoscale forecasting is performed externally by the Penn State NCAR mesoscale model (MM5), which is now a component of the latest Weather Forecast Office (WFO) software release. The MM5 system is configured to produce a 24-hour forecast every 6 hours, in a series of nested grids with the highest resolution set to 1.1 kilometers. Forecast model output can be used by MARSS for meteorological support and 3-dimensional toxic hazard predictions.

The current version of MARSS has been ported to the Linux operating system as part of the Range Standardization and Automation (RSA) program. The RSA MARSS is required to integrate with several legacy instrumentation systems, as well as both the new RSA weather systems and the RSA LAPS and MM5 implementations (the latter is essentially the latest WFO software with local data ingest to support the AF and NASA users).

2. SYSTEM OVERVIEW

The RSA MARSS system consists of a distributed array of interconnected workstations that provides the communications/computational platform and end-user interfaces for the following functions:

- Acquisition and display of lightning data: Lighting Detection and Ranging (LDAR), Launch Pad Lightning Warning System (LPLWS), Cloud-to-Ground Lightning Surveillance System (CGLSS), and Lightning Location and Protection System (LLPS). RSA MARSS is the primary acquisition node for these systems and distributes the data to the RSA Weather system.
- Acquisition, quality control, and display of several dozen meteorological towers reporting up to 6 levels (tower heights range from 16 to 100 meters) of data, including peak and mean speed, direction & directional deviation, and temperature & moisture.
- Acquisition, quality control, and display of six co-located 915 MHz Doppler Radar Wind Profilers and MiniSODARs (one each) and one 50 MHz DRWP, as well as the associated RASS units.
- Acquisition and display of multiple Automated Surface Observing System (ASOS) sites.
- Acquisition and display of AMPS balloon soundings (both synoptic and launch support).
- Automated weather alert monitoring based on user-specified warning criteria.
- Analysis, display, and prediction of the dispersion of toxic “cold” spills of propellant using Ocean Breeze Dry Gulch (OBDG), the Air Force Toxicological Model (AFTOX), Winds On Critical Streamlines (WOCSS), and the Hybrid Particle and Concentration Transport (HYPACT) dispersion model (driven by MM5 forecast output).
- Acquisition, analysis, display and prediction of atmospheric dispersions of rocket engine exhaust and conflagrations (or “hot” spills) using the specified version of Rocket Exhaust Effluent Diffusion Model (REEDM) output.

- Acquisition, analysis, and display of predictions from the Launch Area Toxic Risk Assessment (LATRA) model.

- Acquisition, analysis, and display of predictions from the potential for high order detonation(s) with concomitant window breakage, fragmentation, and casualties using the Blast Damage Assessment Model.

- Display of all toxicological and blast damage effects at specific facilities and critical receptor sites around CCAFS, PAFB, KSC, and VAFB.

- Provides integration and display of RSA meteorological modeling products from the Penn State NCAR Mesoscale Model (MM5), and the Local Analysis and Prediction System (LAPS).

MARSS is designed for a 24 hours per day, 7 days per week mission interval, with sufficient computational, analysis, and data communication capability to provide responsive end-user support during surge periods associated with launch operations or potential toxicological hazard response support.

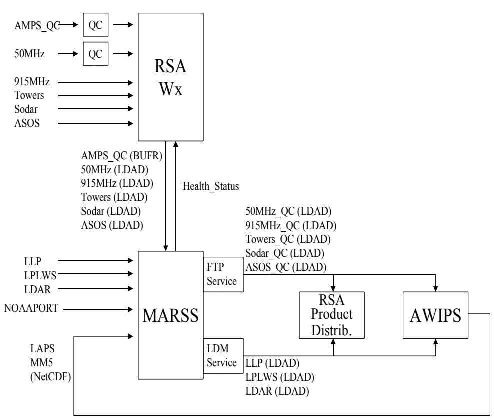

Figure 1. RSA MARSS PPRO data flow.

A block diagram of the overall data flow to and from the PPRO is shown in Figure 1. The LLP system (as shown) represents two different systems delivered at different times to the ER and WR by Global Atmospherics, Inc. The automated profiler QC consists of the Weber-Wuertz algorithm (Weber & Wuertz, 1993), while the 50 Mhz QC in the upper left corner consists of both the Median Filter/First Guess algorithm (Schumann, et al, 1995) and W-W, with an optional manual interface. The AMPS QC interface is a manual editing tool for the Automated Meteorological Profiling System (a GPS-based balloon sounding system), and the direct NOAAPORT interface is not yet implemented.

The incoming data is received in real-time by all active PPROs via serial, FTP, and NFS mounts, and sent to external systems via both FTP and LDM. All PPROs format, archive, and add the QC flags, and then the primary PPRO “pushes” new data immediately to both external systems and available MDS workstations (via an internal MARSS communications protocol). The data sources include one-minute (towers, MiniSODARs, ASOS), 15-minute (915 and 50 Mhz DRWPs), hourly (LAPS and launch support balloon soundings), 4 times per day (MM5) and twice-daily (synoptic balloons) sources. The lightning systems send data as detected, so the PPROs “bin” the incoming data in one-minute blocks. The lone exception is the LDAR system, which requires a dedicated Linux protocol converter to interface to the LDAR network.

Both the PPRO and MDS run under the X-Windows windowing environment, and provide graphical displays, menus, and buttons for all critical functions. Although the main role of the PPRO is unattended data processing and dissemination, the operator PPRO displays and dialogs include:

- Dynamic log window for MARSS-specific logs (Data-Acq/QC, Network Communications, and System Messages) with selectable viewing day (defaults to current).

- Data archive, retrieval, and MDS retransmission GUI with time-selectable parameters for each function.

- MDS status and control GUI, including most recent communication and error status, individual data type transmission control and model/data access permissions.

MARSS uses internal configuration data tables to define available sensors, data types and processing, alert criteria, and MDS attributes (identity, permissions, etc). Many options are user-selectable through the various operator dialogs, however, all the main configuration tables are also directly editable as ASCII text files.

MARSS is designed to run with multiple PPROs operating in a redundant fail-over mode, with one primary and one backup processing all data simultaneously (however, only the primary PPRO transmits data to the MDS workstations). If the primary PPRO's network heartbeat is not detected by the backup PPRO within a specified number of seconds, the backup will automatically take over as the primary PPRO.

The MDS provides multiple user displays, including both text and graphics, for both model output and local meteorological data on a GIS map display, as well as multiple 2-D profile types and 3D visualization (using vis5D). The map and profile displays are configurable for both height and time averaging, and automatically refresh as new data is received from the PPRO.

The RSA MARSS system also provides both integrated color laser hard-copy and outgoing network fax support for all MDS workstations, with local client selection of both print and fax servers (each PPRO is configured as an independent fax server with dual external modems).

MDS workstations may be either locally networked or connected through remote dial-up networking, the only caveat being that certain data products (e.g., each hourly LAPS grid at a single resolution is over 22 Mbytes) are too large to be transferred easily over anything less than a 100BaseTX/FD connection. However, each data type is selectable for transmission to a given MDS; all data except the LAPS and MM5 grids can be transmitted without problems to individual dial-up MDS clients.

3. SYSTEM ARCHITECTURE

The previous ER version of MARSS was more or less a stand-alone system which only interfaced directly to the local launch range meteorological instrumentation systems (e.g., towers, LDAR, etc), and performed almost all other functions (such as mesoscale forecasts and ppp client support) internally as well. Even earlier versions of MARSS were ported from a DEC microVax to HP hardware and a commercial Unix environment, incorporating a combination of in-house code, commercial software, and code supplied by the government customer.

The version discussed here, RSA MARSS, was not only required to support both launch ranges (the ER and WR), but also to integrate with several additional systems (in addition to the legacy range lightning instrumentation systems). These additional systems include the new RSA weather systems developed by the prime RSA contractor, as well as RSA-enhanced versions of the WFO-Advanced weather systems from NOAA's Forecast Systems Lab (FSL). To some extent, the RSA MARSS development was driven by the requirement to both minimize the amount of new code developed and maximize the re-use of legacy MARSS and other government-furnished code. Minimizing life-cycle costs (largely software maintenance costs) was also an important factor.

Based on the above factors, as well as externally-imposed design constraints, the RSA version of MARSS was ported to the GNU/Linux platform on Intel-compatible hardware (in this case, IBM Intellistation Z-Pro dual-Xeon processors as part of the standard RSA inventory). This allowed the replacement of commercial software with freely available open source packages, as well as the equivalent development libraries (e.g., OpenMotif instead of the proprietary version). The previous MARSS Safety Map components were replaced with a full GIS capability using GRASS (the original GIS developed by the US Army, now an active open source project), and the RAMS mesoscale modeling functionality was replaced by the external MM5 interface (currently running on an 8-node, 16-cpu Linux cluster supplied by FSL).

As it was the only Linux platform compliant with the DoD's Defense Information Infrastructure – Common Operating Environment (DII–COE) requirements, the current RSA MARSS Operating System (OS) is RedHat's Advanced Server 2.1 (AS2.1). Numerous GNU programming languages and development tools, as well as many other open source software packages, were used to integrate the updated MARSS code with the new modules and system interfaces:

- RedHat Enterprise Linux – An open source enterprise-ready OS with freely available sources (in keeping with the GNU General Public License).
- DOSEmu – An open source DOS emulation package required to host a binary-only safety model (LATRA).
- Hylafax – A client/server network fax package that supports access controls, multiple clients, etc.
- CUPS – The Common Unix Printing System uses modern network protocols, access controls, configurable classification banners, etc.
- ImageMagick – An open source suite of image manipulation tools with dedicated command-line components for individual tasks (used to display fax previews and other dynamically-generated graphical output).
- GRASS and associated libraries – The original GIS developed by the Army, including a map manager GUI, permanent mapsets, and the associated geographic support libraries for map projections, shapefiles, etc.
- NetCDF – Custom ingest formatters were built using the UCAR NetCDF libraries and FSL's LAPS CDL data definitions.
- Python & Bash – Extensive use of scripting to pass arguments, environment variables, and data files between software components allows ease of maintenance, testing, and troubleshooting.

Previous model execution interfaces were incorporated, as well as new user, control, and display interfaces for the newly hosted models such as WOCSS and Aftox. The Hypact model retains the legacy execution and Vis5D display interface, since the previous RAMS code was reused (incoming MM5 grids are reformatted to RAMS format).

Additional reused software components include the alert monitoring, archive manager, and data manager modules. Motif windowing widgets were reused with only minor changes, and almost all legacy Fortran codes were rebuilt transparently with G77 (the GNU Fortran 77 compiler), with the exception of the WR legacy Aftox code, which required certain F90 constructs and VMS extensions not supported by G77 (the commercial Portland Group Fortran compiler was used instead). The new Aftox user interface was developed with Tcl/Tk.

3.1 System and Data Interfaces

The bulk of the RSA weather system (RSA WX) and range instrumentation are external to MARSS, and consists of a new suite of local instruments (the meteorological towers, Doppler Radar Wind Profilers, and MiniSODARS mentioned above), along with the RSA assets required to support the acquisition, dissemination, and storage of the associated data, as well as the additional NOAAPort ingest and data products produced by the RSA systems from FSL. The latter includes large quantities of external data (model grids, surface and satellite observations, and upper air data), as well as the hourly gridded analysis produced by LAPS, and the MM5 forecast grids (produced every 6 hours), all displayable in AWIPS (principally D2D) on the RSA weather workstations. Details of the specific data sources ingested by RSA MARSS are listed in Table 1.

While RSA WX is the primary ingest interface for all the new RSA instrumentation, MARSS is still responsible for ingest and display of the various range lightning systems (three at the ER, one at the WR). Each system produces different data types and formats (mostly ASCII), and has a different physical interface:

- Lightning Location & Protection System (LLPS, Western Range) – Essentially a Global Atmospherics LP2000 system connected through an RS-232 serial-to-IP interface for each PPRO. The data format is GAI's Universal ASCII Lightning Format (UALF).

- Cloud-to-Ground Lightning Surveillance System (CGLSS, Eastern Range) – Similar to LP2000 system, also from GAI; provides strike location data (format a subset of UALF).

- Launch Pad Lightning Warning System (LPLWS, Eastern Range) – Detects dangerous electrical charge buildup, and provides the following data: Field Mill Grid data, Field Mill Value Table data, and Field Mill Center of Charge data (instrument-specific ASCII format).

- Lightning Detection And Ranging (LDAR, Eastern Range) – Legacy 3-Dimensional lightning strike detection system (early GAI model). Provides 3-D grid locations of lightning strikes (ASCII format).

All incoming lightning data is ingested as received by the PPROs, and binned into one-minute data packets before archiving and transmission. The lone exception to the above is LDAR, which still runs on its own legacy network (protocol an OSF variant). A dedicated Linux protocol converter is used to “sniff” the data packets on the LDAR network and re-frame the data as TCP/IP packets. None of the lightning data is quality-controlled by MARSS, however, any existing quality information provided by the system is preserved. All lightning data is transmitted immediately via LDM to both RSA WX and AWIPS assets, as well as to available MDS clients. MARSS also monitors each of the above lightning systems (for both connectivity and data receipt) and provides a heartbeat on the RSA WX interface.

An externally-defined weather data interface is used (shown in Fig. 1 as LDAD) for the remainder of the local data, consisting of ASCII files (in comma-separated value format) for all data types except the AMPS balloon data, which is BUFR-encoded prior to receipt by the PPRO. Local LDAD data is transmitted via FTP between the PPROs and the RSA WX Ingest and Product Distributor functions.

The interfaces for the LAPS and MM5 model grids make use of the standard AWIPS client mode of mounting the AWIPS data server via NFS for the LAPS grids, and the head-node of the MM5 modeling cluster for the MM5 forecast grids.

3.2. Core Software Architecture

Figure 2 depicts the detailed communications, both control and data flow, between the core PPRO software modules (in DoD software parlance, Computer Software Configuration Items and Computer Software Components), as well as external data sources and the MDS CSCI. Data received and processed by the PPRO CSCI is reformatted to an internal binary format that seeks to generalize data into different categories. A data source may report data corresponding to one or more of the RSA MARSS data types in Table 1.

The RSA MARSS is designed to run on a computer platform supporting multiple processes executing in parallel. Most software components have been implemented as separate, continuously executing processes referred to as “core processes”. Core processes may also spawn temporary helper processes to perform a specific task. These processes will run for a short time and then terminate, returning status information to the parent process.

The core processes react to various events to perform their functions, i.e., the basic design is that of an event-driven system. These events take different forms and are generated both externally and internally to MARSS. Each event is defined in terms of the condition(s) that trigger it, the originating component, the destination component and the effect.

On the MDS side, the Data Manager is the main core component that receives, manages, and stores incoming data and local model output, as well as provides data playback capabilities. Table 2 describes the operational states and modes of the MDS component of MARSS. The normal operating mode is real-time, with a configuration option for running in a “monitoring-only” mode. Since MARSS was never allocated any hard real-time requirements, no special real-time Linux kernel extensions are employed. The MDS also includes the capability to run in replay mode, where historical data is replayed through the models and associated displays (current data is still received and processed normally).

The MDS provides numerous displays of both data and model output, including tabular data, vertical profiles, and map displays (specific 3D output is viewable with Vis5D). Wind direction and speed, temperature, relative humidity, and pressure can be viewed in various text formats through the Tabular Displays option. Pre-configured tower definitions are provided with both full data and one-line-per-level options.

The Radar Wind Profiler display provides a mechanism for displaying vertical profiles of wind and temperature data reported by the 50 Mhz and 915 Mhz profilers, as well as the MinSODARs. The Wind Barb Time Series allows the user to display data for a single profiler over a time period of up to 24 hours, while Wind Barb Profiler Series allows the user to display data for all profilers of a single type for a specified time.

The GRASS map display allows geographical background and all data representations to be displayed by means of map layers. General geographical information is available as raster, vector lines, and vector area layers. The following custom layers are used to display MARSS data: Data Labels, Wind Barbs, Wind Field, Vertical Summary, Lightning Strikes, Velocity Divergence Contours, Ocean Breeze/Dry Gulch, AFTOX, REEDM, Blast % Breakage, and Blast Overpressure. All layers provide specific user-adjustable parameters, including colors.

For example, the wind barb and wind field map layers both provide user-selectable minimum and maximum heights, which automatically height-average if multiple levels are found between the min and max height values. The user can also select the instrument source (for the wind barb layer) or the wind field model source grid (for the wind field layer), as well as colors, data labels, and QC restrain (for the wind field only).

3.3. System Integration and performance

In addition to the afore mentioned instrumentation and RSA WX interfaces, MARSS is also required to host several legacy safety models for assessing both toxic and blast over-pressure hazards and risks. Most of these codes were built as native Linux applications, and multiple versions of several models are hosted within MARSS and made available through individual model execution managers, mainly to support pre- and post-launch analyses and model development by range safety personnel.

As of this writing, the system is in the final stages of range integration and preparation for qualification testing on the ER, with full system-integration testing to follow on the WR early in 2005. As long as the required MARSS data sources are available and local network performance is nominal, the overall performance of MARSS is excellent. All data is processed and transmitted by the PPROs with only minimal system load and occasional peak network traffic (i.e., for the large model grids). Both PPRO and MDS components have been observed to run unattended for periods of several months already, continuously processing data and handling user requests. These systems went through several incremental MARSS software upgrades during integration without either a reboot or loss of data.

Kernel hardware drivers have been observed to cause problems (due to the age of the RedHat 2.4.9 kernel compared to the IBM hardware platform), however, initial driver upgrades have been performed, with an eventual upgrade to kernel 2.6 planned.

4 SUMMARY AND CONCLUSIONS

The RSA MARSS project is the result of a highly successful technology transfer from innovative research to operational product, and is an example of achieving maximum performance and flexibility in a cost-effective manner by utilizing a combination of existing software, available open source packages, and custom “glue” code to supply the framework to control and execute the various software functions.

The current MARSS system integrates a combination of open source software, freely available scientific codes, and both new and legacy software, on commodity PC hardware. The low-cost integration of both meteorological and hazard models provides operational weather and safety users access to the same tools and displays, thus maximizing accurate and consistent information flow to the appropriate organizations, ensuring the same tools are used for both mission planning and hazard analysis, as well as emergency response. The built-in fax capabilities further enhance communications between operational safety personnel and outside agencies.

The resulting system is high in performance and usability, as well as low in life-cycle costs. The modular and scalable system architecture allows easy integration of new data types, safety tools, and map displays, as well as additional preprocessors and display stations, as operational requirements change.

REFERENCES

Schumann, Robin S., G. E. Taylor, F. J. Merceret, T. L. Wilfong, 1999: “Performance Characteristics of the Kennedy Space Center 50 MHz Doppler Radar Wind Profiler Using the Median Filter/First Guess Data Reduction Algorithm” *J. Atmos. Oceanic Technol.*, Volume 16.

System Specification for the Range Standardization and Automation Meteorological and Range Safety Support System (RSA MARSS), Revision 3 (draft), ENSCO, Inc., 3009-02-DR-001-0003, Dec 2004.

Weber, B.L., and D. B. Wuertz, et al, 1993: “Quality Controls for Profiler Measurements and RASS Temperatures”, *J. Atmos. Oceanic Technol.*, Volume 10.

Data Type	Description
Tower	Sensor system identification, sensor identification, observation time, number of records, altitude of observation, 1 minute average (x and y), temperature, relative humidity, wind direction, wind speed, gust speed, gust direction, net radiation, soil moisture, std deviation of horizontal wind direction (1, 5 and 10 min), mean speed (5 and 10 min), mean direction (5 and 10 min), pressure (if provided), rain rate, dewpoint temperature, QC flags
ASOS	Sensor system identification, sensor identification, observation time, number of records, altitude of observation, sky condition, visibility, tower visibility, present weather, urgent weather, sea level pressure, dew point, relative humidity, wind speed, wind direction, magnetic wind speed, magnetic wind direction, altimeter pressure, density altitude, pressure altitude, remarks, rain rate, temperature, QC flags
MiniSODAR (DASS)	Sensor system identification, sensor identification, observation time, number of records, altitude of observation, mix height, unoise, vnoise, wnoise, number of gates, gate number, wind direction, wind speed, gust speed, gust direction, vertical wind component (W), sdt deviation of W, sample obs of W, signal return intensity of W, signal to noise ratio of W, east/west wind component (U), std deviation of U, sample obs of U, signal return intensity of U, signal to noise ratio of U, north/south wind component (V), std deviation of V, sample obs of V, signal return intensity of V, signal to noise ratio of V, QC flags
Lightning_Strike	Latitude and Longitude of a detected lightning strike, charge strength, quality indicators
LPLWS -Lightning Strike -Field Mill Sensors -Filed Mill Grid	System identification, observation time, latitude, longitude sensor identification, electrical potential LPLWS field mill grid values
LDAR	Center of charge
915 Mhz Profiler - RWP - RASS (Radio Acoustic Sounder System)	Sensor system identification, sensor identification, observation time, number of records, altitude of observation, number of gates, gate number, wind speed, wind direction, velocity of radial beam 1 (1), number of obs in 1, signal to noise ratio of 1, velocity of radial beam 2 (2), number of obs in 2, signal to noise ratio of 2, velocity of radial beam 3 (3), number of obs in 3, signal to noise ratio of 3, velocity of radial beam 4 (4), number of obs in 4, signal to noise ratio of 4, velocity of radial beam 5 (5), number of obs in 5, signal to noise ratio of 5, QC flags gate number, temperature (T), corrected temperature (Tc), vertical wind component (W), signal to noise ratio of T/Tc/W, number of T obs, number of Tc obs, number of W obs, QC flags
50 Mhz Profiler -RWP -RASS	Same as 915 Mhz Profiler
AMPS	
National Surface Observations	Wind speed/direction, gust, temperature, dew point, current weather description, cloud coverage and ceilings
National Upper Air Soundings	
Buoy	Wind speed/direction, pressure, temperature, dew point and sea surface temperature
LAPS	3-d gridded analyses of 42 meteorological variables (surface winds extracted)
MM5	MM5 model forecasts
REEDM	REEDM model isopleths
BLASTI	BLASTI Text input
BLASTO	BLASTO Text output
BLASTG	Percent breakage points, blast overpressure contours

Table 1. MARSS Data Types

	Modes		
Capabilities	**Real-Time**	**Historical Data Replay**	**Alert Monitor Client**
Meteorological and Model Data Capability	Process all meteorological and model output data from PPRO, store them in the local archive and provide them to all other MDS capabilities	Process all meteorological and model output data from PPRO, store them in the local archive. Retrieve meteorological data from the local archive as specified by the local user and provide them to all other MDS capabilities	Unavailable
MDS Network Communications	Normal function	Normal function	Normal function
Map Displays	Normal function	Normal function and displaying historical data.	Unavailable
Tabular Data Display	Normal function	Normal function and displaying historical data.	Unavailable
Model Displays	Normal function	Normal function	Unavailable
Log and Status Display	Normal function	Normal function	Normal function
Facsimile Transmission	Normal function	Normal function	Normal function
User Interface	All controls for system capabilities enabled	Data management interfaces display date/time of currently loaded data and status of replay. Replay controls change appearance and availability.	All controls for Alert Monitoring enabled
Lightning Display	Available	Available	Unavailable
Data Monitoring	Available	Available and monitoring historical data.	Available

Table 2. Operating Modes and Capabilities of the MARSS MDS

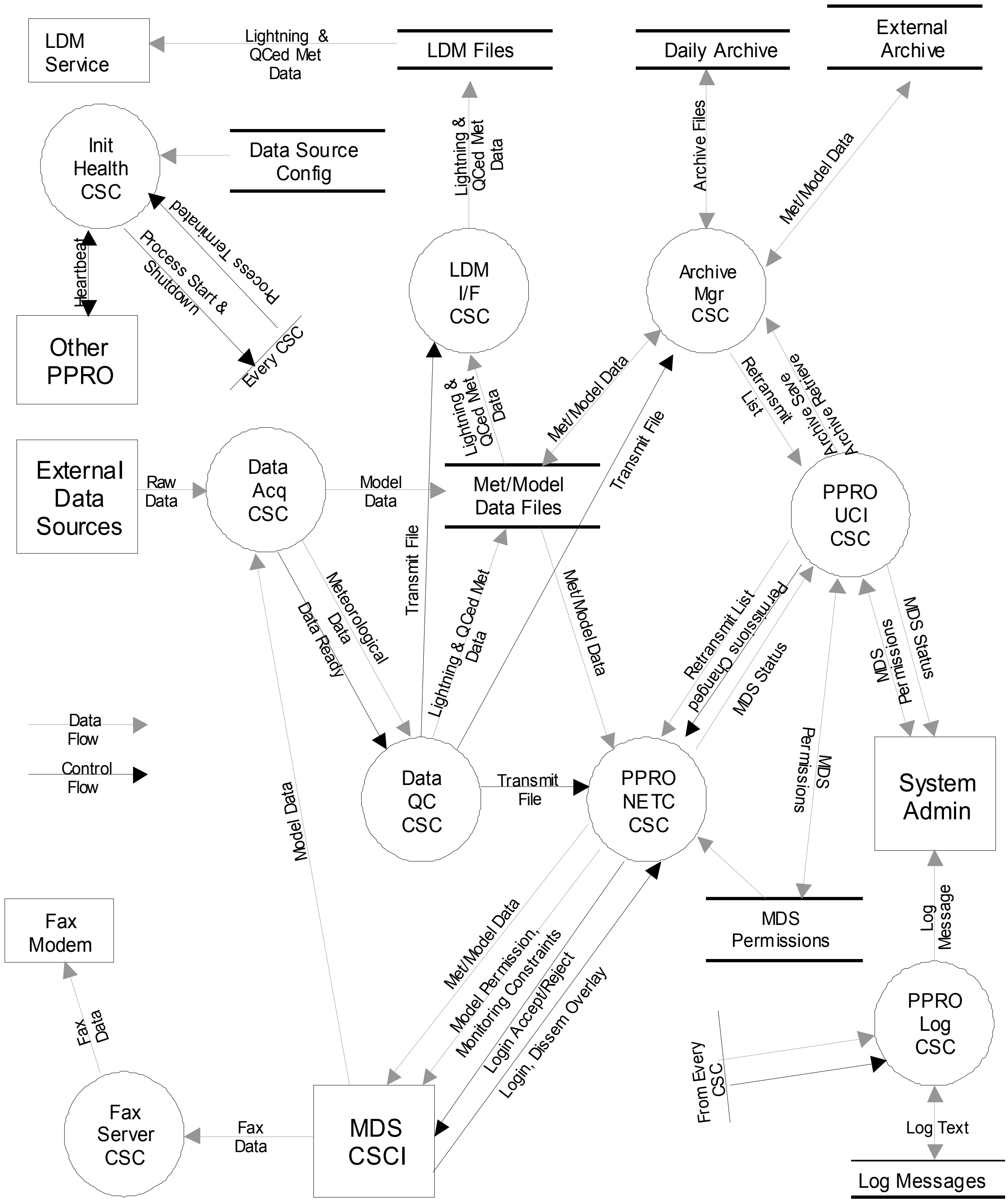

Figure 2. Detailed MARSS/PPRO Data and Control Flow